

| REPORT DOCUMENTATION PAGE  |                         |                                |   | Form Approved<br>OMB No. 0704-0188                          |   |
|--|-------------------------|--------------------------------|---|---|---|
| <p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p>   |                         |                                |   |   |   |
| 1. REPORT DATE (DD-MM-YYYY)<br>30-03-2004  |                         | 2. REPORT TYPE<br>Final Report |   | 3. DATES COVERED (From - To)<br>October 2002 - October 2003 |   |
| 4. TITLE AND SUBTITLE<br>Determining Source Levels, Sound Fields, and Body Sizes of Singing Humpback Whales (Megaptera novaeangliae) in the Hawaiian Winter Grounds  |                         |                                | 5a. CONTRACT NUMBER                         |   |   |
|  |                         |                                | 5b. GRANT NUMBER<br>N00014-02-1-1058        |   |   |
|  |                         |                                | 5c. PROGRAM ELEMENT NUMBER                  |   |   |
| 6. AUTHOR(S)<br>Pack, Adam A., Potter, J., Herman, L. M., Hoffmann-Kuhnt, M., Deakos, M. H.  |                         |                                | 5d. PROJECT NUMBER                          |   |   |
|  |                         |                                | 5e. TASK NUMBER                             |   |   |
|  |                         |                                | 5f. WORK UNIT NUMBER                        |   |   |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>The Dolphin Institute<br>420 Ward Ave., Suite 212<br>Honolulu, HI 96814  |                         |                                | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER |   |   |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>Office of Naval Research<br>800 N. Quincy St.<br>Arlington, VA 22217-5000   |                         |                                | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>ONR     |   |   |
|  |                         |                                | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)   |   |   |
| <p>12. DISTRIBUTION/AVAILABILITY STATEMENT<br/>Distribution Unlimited</p> <p style="text-align: center;"><b>DISTRIBUTION STATEMENT A</b><br/>Approved for Public Release<br/>Distribution Unlimited</p>  |                         |                                |   |   |   |
| 13. SUPPLEMENTARY NOTES<br>N.A.  |                         |                                |   |   |   |
| 14. ABSTRACT<br>The stereotypical stationary posture adopted by male humpback whales producing song suggests they are attempting to optimize transmission range. Over 23 days between Jan. 28 and Apr. 2 2003, we measured the sound fields of singers using divers equipped with rebreather scuba. A custom-designed "Aquahead" system reliably located singers to within 50 m. Fifty seven singers were located using the Aquahead from distances as far away as 6.1 km in as short a time as 3 min. Divers recorded song using digital video cameras while simultaneously measuring depth and range to a singer's head using handheld ultrasonic range finders. Whale body lengths were obtained using videogrammetry. Source levels were measured up to 203 db re 1micro Pa @ 1m. Up to a 16 dB difference between frontal and lateral intensities (2.2 kHz) was found indicating that song was most intense at locations directly in front of the singer's rostrum. Body lengths were obtained for 18 singers. Sizes ranged from 10.64 to 13.55 m. A larger dataset is required to compare source levels and sound fields of particular units with whale body size. |                         |                                |   |   |   |
| 15. SUBJECT TERMS<br>Humpback whale, Whale song, Humpback whale source levels, Humpback whale sound fields   |                         |                                |   |   |   |
| 16. SECURITY CLASSIFICATION OF:  |                         |                                | 17. LIMITATION OF<br>ABSTRACT<br><br>UL     | 18. NUMBER<br>OF<br>PAGES<br><br>4.5                        | 19a. NAME OF RESPONSIBLE PERSON<br>Adam A. Pack, Ph.D.    |
| a. REPORT<br>Unclass.  | b. ABSTRACT<br>Unclass. | c. THIS PAGE<br>Unclass.       |   |   | 19b. TELEPHONE NUMBER (Include area code)<br>808-593-2211 |

Standard Form 298 (Rev. 8/98)  
Prescribed by ANSI Std. Z39.18

20040405 068

FINAL REPORT

GRANT #: N00014-02-1-1058

PRINCIPAL INVESTIGATOR: Dr. Adam A. Pack

INSTITUTION: The Dolphin Institute

GRANT TITLE: Determining Source Levels, Sound Fields, and Body Sizes of Singing Humpback Whales (*Megaptera novaeangliae*) in the Hawaiian Winter Grounds

AWARD PERIOD: 20 October 2002 - 19 October 2003

OBJECTIVES: To provide detailed information on humpback whale source levels and acoustic fields in both the vertical and horizontal plane during song production, and to measure the body lengths of humpback whale singers to examine the association of source levels and sound fields with body sizes.

APPROACH: Divers using rebreather SCUBA descend to the vicinity of a singing whale to measure the source levels and acoustic field around the whale as it vocalizes. The use of rebreathers reduces noise and bubble production, typically associated with open circuit SCUBA. Additionally, the rebreathers allow for longer and more frequent dives at depths up to approximately 30 m. Divers record song on digital video cameras in underwater housings outfitted with calibrated hydrophones and measure the distances from the camera to the whale using hand-held high frequency range finders. Measurements of the whale's size are obtained using an underwater videogrammetric technique developed and pioneered by researchers of The Dolphin Institute (Spitz, Herman & Pack, 2000; Spitz, Herman, Pack & Deakos, 2002). All field research is carried out under Hawaii State Permits issued to L.M. Herman and A. A. Pack, and National Marine Fisheries Service Federal Scientific Research Permit #707-1531-00 to L.M. Herman, University of Hawaii. The data collection takes place in the waters adjoining west Maui, where North Pacific humpback whales are abundant during the winter months (Herman et al., 1980; Mobley et al., 1999). Because the migratory timing of male humpback whales to the winter grounds is staggered by age class, singers are recorded and measured during the early, middle, and late portions of the winter season in an attempt to sample individuals of different sizes and maturity levels. Details of our approach and methods follow.

*Locating singers.* Singing whales are located using an ARL custom designed two-element hydrophone array termed Aquahead. It consists of twin calibrated and shielded C54 hydrophones mounted 0.83 m apart on the ends of an inverted hand-held metal T-bar. The Aquahead is of small size and is immersed in the water from the side of the research boat. Acoustic signals are amplified and transmitted to a set of stereo headphones. One experimenter rotates the array about its vertical axis while another listens on the headphones and reports both the direction in which the song is loudest and a rating of perceived amplitude on a 5-point scale (5 = loudest) that is roughly translated into an approach distance. The boat motors in the indicated direction and distance (as measured by GPS) and the Aquahead is redeployed. Over a series of such maneuvers, the singer is approached by the boat to within approximately 25-50 m.

DISTRIBUTION STATEMENT A:  
Approved for Public Release -  
Distribution Unlimited

*Rebreather deployment.* Once the singer is localized, a snorkeler enters the water, confirms that the singer is stationary and alone, and positions himself directly above the whale. Two rebreather-certified divers wearing semi-closed Draeger-dolphin rebreathers then enter the water, swim to the location of the snorkeler, and descend to the singer's depth (ca. 20-30 m). Each diver is equipped with a Sony TRV900E digital video camera in a Sony underwater housing with hydrophones with manual record levels. Each diver also carries a high-frequency (200-400 kHz) sonar device (Speedtech Depthmate). At depth, one diver records song and video images while remaining stationary as an acoustic reference. The other diver records song and video images while moving slowly around the whale's head. Approximately every 5-10 sec, each diver measures and records on the video camera the distance from the camera to the whale and to the surface using the range finders. The digital display on the Speedtech of each measured distance is recorded on the camera. The exact moment of triggering is captured on the videotape by a click sound from the sonar device. Using these measurements in conjunction with the angle of the camera relative to the whale, singer acoustic fields and source level can be determined. The digital video camera records at 44.1 kHz with DAT quality. At ranges of more than 5 m, near-field effects do not significantly distort the recordings, since the effective size of the source-generating region of the whale is not anticipated to exceed 1 m in overall diameter. Most of our recordings are taken at ranges of 10-15 m. Both horizontal and vertical beam patterns are generated from the array of measurements in relation to the whale's location.

*Whale size measurements.* Data to determine whale size is collected by the snorkeler at the surface who carries the same sonar device as the divers and a digital video camera (Sony DCR-TRV-7) in an underwater housing (Jay-Mar VM-6000). The snorkeler captures the whale's full body length from lateral or topside views taken at right angles to the whale as it straightens its body when initiating surfacing (typically while singing, humpbacks are canted head-downward). Multiple images are obtained to allow for reliability checks on measurements (using a coefficient of variation statistic), and to obtain as many images as possible that are without bending or curvature of the whale's body. The sonar device is used to measure distance from the camera to the whale, as with the acoustic measurements described earlier.

*Data processing and analyses.* Data processing takes place subsequent to fieldwork. Acoustic data is analyzed using MATLAB sound analysis software. All measured distances are input into databases together with data on sound pressure levels for different song units and phrases of individual singers. Source levels are determined as a function of received amplitude, propagation characteristics, and measured distance from the video camera system to singer. Sound fields are mapped as a function of the source levels obtained from the roving diver's video camera relative to those obtained by the stationary diver's system at different distances relative to a singer's head. The data are analyzed separately for different song units to examine how propagation and received levels of these units may vary. The body lengths of singers are measured using PhotoShop and DV tools, based on individual frames revealing the full body length of the whale (see Spitz et al., 2000 for details). The size data from individual singers are integrated with corresponding source level data to examine for any correlation. A regression analysis determines the relation of individual singer size to source level.

ACCOMPLISHMENTS: Fieldwork was conducted daily or nearly so over 23 days split into three periods in waters off West Maui during the winter and spring of 2003. The three periods of data collection were from Jan. 28 to Jan. 31 (4 days), Feb. 18 to Feb. 26 (9 days), and Mar. 24 to Apr. 2 (10 days). A total of 57 humpback whale singers were located using the Aquahead from distances as close as 0.3 km to as far away as 6.1 km ( $M = 2.1$  km). Singers were localized and approached to within 50 m in as short as 3 min ( $M = 20.1$  min, range = 3 min - 63 min). Rebreather divers were deployed successfully with 18 lone singing whales, and in most instances the roving diver was able to complete a circuit around the singer's head of  $180^\circ$  or more. Other localized singers were discovered to be either traveling (Frankel et al., 1995), accompanying a mother-calf pair (Herman & Tavorga, 1980; Baker & Herman, 1984), or being visited by another male whale (see Darling & Berube, 2001). In these instances, there was no opportunity for rebreather deployment. Body lengths, as determined through our underwater videogrammetric technique were obtained on 12 of the singers recorded by the rebreather divers.

CONCLUSIONS: Source levels were obtained on a variety of units from both cameras. Source levels were recorded up to 203 db re  $1\mu\text{Pa}$  @ 1m. This is considerably higher than that reported previously by researchers (e.g., 144-174 db re  $1\mu\text{Pa}$ , Richardson et al., 1995). Using our rebreather technique we measured directly the distances between the recording camera and the singer using the hand-held range finder. Distances to singers were as close as 10 m on some occasions. Furthermore, the video record allowed for the precise location of the recording device relative to the singer to be determined.

We employed two methods to determine sound fields. First, we used intra-camera dB differences for each unit (e.g., in one dive, there were 128 units recorded on both cameras). We also used intra unit dB differences on each camera for the same type of unit as the roving diver moved across the frontal plane of the whale. Using these methods, analyses revealed up to a 16 dB difference between frontal and lateral intensities (2.2 kHz) indicating that song was not projected with uniform intensity omnidirectionally around the whale but rather that the sound field was most intense at locations directly in front of its canted rostrum (cf. Levenson, 1972). As expected, the sound field varied as a function of frequency with smaller beam pattern differences at lower frequencies.

Body lengths determined using our underwater videogrammetric technique, were obtained for six singers during our pilot work in 2002 and on an additional 12 singing humpback whales in 2003. Coefficients of variation for individuals sized multiple times were less than 5% with a median CV of 1.60% indicating a high degree of reliability of the technique (see also Spitz et al., 2000; Spitz et al., 2002). Sizes ranged from 10.64 m to 13.55 m ( $M = 12.22$  m,  $SD = 0.87$ ). In relation to estimated levels of sexual maturity, Spitz et al. (2002) showed that a male humpback whale of 10.7 m in length has a probability of sexual maturity of 0.1, a male of 11.0 m, a probability of sexual maturity of 0.3, and a male of 11.9 m, a probability of 0.9. Our data showing three whales below 11.0 m and 14 whales above 11.9 m in length indicates a high probability that measured singers were both sexually immature and mature. The relation of singer size to source level and sound field will require a larger dataset than was currently available under this contract.

SIGNIFICANCE: Recent concerns about the effects of underwater anthropogenic noise on whales and dolphins have prompted action to better understand the communication and hearing systems of various species. The National Marine Fisheries Service Recovery Plan for the humpback whale and the Hawaiian Islands Humpback Whale National Marine Sanctuary Management Plan have specifically identified the endangered humpback whale as a candidate of concern in regard to effects of anthropogenic noise. The stereotypical head-canted-downward posture adopted by stationary male humpback whales while "singing" on their breeding grounds suggests that they are attempting to optimize the song's transmission range. This report's findings on the source levels and sound fields associated with whale song is vital for determining how anthropogenic sounds may affect song transmission and reception by listening whales.

PATENT INFORMATION: No patents have been filed at this time.

PUBLICATIONS AND ABSTRACTS. Pack, A. A., Potter, J. R., Herman, L. M., Deakos, M. H., & Hoffmann-Kuhnt, M. (2003). Determining source levels and sound fields of singing humpback whales (*Megaptera novaeangliae*) on the Hawaiian wintering grounds. Abstract. Conference on the Environmental Consequences of Underwater Sound, May 12-16, San Antonio, TX. Pp.31-32.

#### REFERENCES

- Baker, C. S., & Herman, L. M. (1984). Aggressive behavior between humpback whales wintering in Hawaiian waters. *Canadian Journal of Zoology*, 662, 1922-1937.
- Darling, J.D., & Bérubé, M. (2001). Interactions of singing humpback whales with other males. *Marine Mammal Science*, 17, 570-584.
- Frankel, A.S., Clark, C.W. Herman, L.M. & Gabriele, C.M. (1995). Spatial distribution, habitat utilization, and social interactions of humpback whales, *Megaptera novaeangliae*, off Hawaii, determined using acoustic and visual techniques. *Canadian Journal of Zoology* 73, 1134-1146.
- Herman, L. M., Forestell, P. H., & Antinaja, R. C. (1980). The 1976/77 migration of humpback whales in Hawaiian waters: composite description. *Marine Mammal Commission Rep. No. MMC-77/19*, WA.
- Herman, L. M., & Tavorga, W. N. (1980). The communication systems of cetaceans. In L. M. Herman (Ed.), *Cetacean behavior: Mechanisms and functions*, (pp. 149-210). New York: Wiley Interscience.
- Levenson, C. (1972). *Characteristics of sound produced by humpback whales (Megaptera novaeangliae)* (NAVOCEANO Technical Note No. 7700-6-72). Washington, DC: Naval Oceanographic Office.
- Mobley, Jr., J. R., Bauer, G. B., & Herman, L. M. (1999). Changes over a ten-year interval in the distribution and relative abundance of humpback whales (*Megaptera novaeangliae*) wintering in Hawaii. *Aquatic Mammals*, 25, 63-72.
- Richardson, W. J., Greene, C. R., Jr., Malme, C. I., & Thomson, D. H. (1995). *Marine mammals and noise*. San Diego, CA: Academic.
- Spitz, S. S., Herman, L. M., & Pack, A. A. (2000). Measuring sizes of humpback whales (*Megaptera novaeangliae*) by underwater videogrammetry. *Marine Mammal Science*, 16, 664-676.
- Spitz, S. S., Herman, L. M., Pack, A. A., & Deakos, M. H. (2002). The relation of body size of male humpback whales to their social roles in the Hawaiian winter grounds. *Canadian Journal of Zoology*, 80, 1938-1947.